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PREDICTION OF PILLAR LOAD - PHASE I - UNDERGROUND SERVICE/GARAGE STATIONS

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by

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ABSTRACT

In mining engineering the problem of designing underground service/garage stations arises frequently. In these cases it is important to be able to predict the load carried by the pillar between two openings.

Using the finite element method a parametric study of the influence of opening and pillar dimensions as well as the field stresses, on the pillar load was carried out.

Engineering empirical equations were found which permit an accurate determination of pillar load as a function of the parameters.

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DÉTERMINATION DE LA CHARGE DU PILIER - PHASE I - STATIONS SOUTERRAINES DE GARAGE ET DE SERVICES

par

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RÉSUMÉ

La création de stations souterraines de garage et de services pose souvent un problème en génie minier. Il est important dans ces cas de pouvoir prédire la charge appliquée sur le pilier entre deux excavations.

On a effectué une étude paramétrique, à l'aide de la méthode des éléments finis, de l'effet qu'ont les champs de contraintes et les dimensions du pilier et de l'excavation sur la charge du pilier.

Des équations empiriques permettant de déterminer de façon précise la charge du pilier ont été établies en fonction des paramètres.

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INTRODUCTION

In underground mines, a series of openings are made for ore extraction and service purposes, including shafts, drifts, crusher chambers, bins, garage or service stations, and stopes. Mining engineers have to determine optimum clearances between openings and design for the optimum stope and pillar sizes. Rule-of-thumb or semi-empirical formulae are generally applied in practice because analytical techniques are not available. This is especially true for multiple openings. Due to the nature of rock masses, and complexities of opening geometries, it is impossible to analytically formulate equations to solve mining problems.

Since the mid 1960's, rapid development of numerical methods for engineering design has taken place. The methods include the finite element, boundary element, and displacement discontinuity approaches. Among these the finite element method is the most popular and sophisticated tool for stress analysis. It can handle complex boundary conditions, loading systems and material properties. Hence, this technique is used in this study for predicting pillar load.

At present, such numerical techniques are not widely used in the mining industry because these require a large computer to handle practical problems. Most mining firms do not have a computer which can handle scientific applications since such computers and their associated communication systems are expensive. Further, most mines are located in remote areas. In addition, numerical modelling requires personnel with a good theoretical background to analyse results and properly apply them to mine design and ground stability evaluation within their limitations.

A parametric study was carried out for obtaining engineering equations for preliminary mine design and planning purposes, based on the finite element simulation. The study will be divided into four phases.

Phase I will deal with pillar load between two symmetrical rectangular openings in a medium with no body weight under field stress loadings.

Phase II will deal with pillar load in blasthole mining operations.

Phase III will deal with pillar load in sill/crown pillar.

Phase IV will deal with pillar strengths - case histories and back analyses.

The objective of this report, on Phase I, is to provide an engineering equation for predicting pillar loads between two symmetrical rectangular openings. The objective is to make it possible for mining engineers to determine the optimum clearances between two openings, with particular application to underground service/garage stations.

ANALYSIS

Assumptions

In this study, the following assumptions were made:

1. Two dimensional plane strain finite element analysis. This analysis is inexpensive and the results are considered to be conservative compared with those from three dimensional analysis.
2. For a first approximation in hard/brittle rock mining conditions at depth, a linear elastic, isotropic homogeneous material was assumed.
3. The change of body weight across the height of openings was neglected, assuming the height of the opening was small compared to the depth below the surface, and the resultant force on opening surfaces is zero. Therefore, stresses are independent of material elastic constants and stress distribution is the same for both plane strain and plane stress conditions (1,2).

Figure 1 shows two symmetrical rectangular openings and loading conditions in an infinite medium. Based on the assumptions made, it was proven (2) that the elastic constants have no effect on stress distributions. Therefore, from Fig. 1, stresses around the openings are influenced by geometry and loading parameters, viz, x, y, W, L, H, p and q. These parameters will be used as a base for determining engineering equations.

Finite Element Simulation

Figure 2 shows a typical model used in this study. Due to symmetrical geometries, only half of the pillar and one opening were modelled.

A total of sixty finite element models were run using the SAP2D (3) and MRL's computer (VAX 11/750). Non-dimensional parameters were input, i.e., $x = x/L$, $y = y/L$, q/p, $E = 1.0$, $\gamma = 0.0$, $\nu = 0.0$ (E = modulus of elasti-

city, γ = mass density, and ν = Poisson's ratio). A parametric study was made for the following cases:

1. H/L = 0.25; W/L varies from 0.125 to 5; p = 1,0; q = 0,1
2. Same as 1, but H/L = 0.5
3. Same as 1, but H/L = 1.0

Results

The results of pillar loads from cases 1 to 3 are combined and shown in Figs. 3 and 4.

Pillar Load Under Vertical Stress Field

Figure 3 shows variation of the perturbation pillar loads with ratios of pillar height to opening width for the case of applied vertical field stress only, i.e., p = 1, q = 0. It can be seen that pillar load exponentially increases from zero to unity as pillar width/opening ratio, W/L, is increased from zero to 3, and is equal to unity when W/L ranges from 3 to infinity. It also indicates that the smaller the ratio of H/L the greater the perturbed pillar loads. This implies that the stresses induced by excavation of each opening are not influencing each other when the pillar width is greater than 3 times the opening width. Thus, the perturbed loads generated by the excavation when H/L is small can be used in a conservative design approach.

Various functions were formulated in conjunction with the non-linear least square techniques. The relationship between the perturbation pillar load and pillar opening dimensions can be found as follows:-

$$\frac{P_1}{pL} = 1 - (a_1 Z + b_1)e^{-c_1 X} - (1 - a_1 Z - b_1)e^{-d_1 X} \qquad (1)$$

where:

P_1 = perturbation pillar load caused by excavation in an infinite medium which is subject to the vertical stress field only.

p = vertical stress field

L = opening width

Z = H/L

X = W/L

H = pillar height

W = pillar width

$a_1 = 0.4$

$b_1 = 0.4$

$c_1 = 2$

$d_1 = 16$

e = exponential function

Pillar Load Under Horizontal Stress Field

Figure 4 shows variation of the perturbation pillar loads with ratio of pillar height to opening width for the case of applied horizontal field stress only, i.e., p = o, q = 1. It indicates that the perturbation pillar loads are in a state of tension and increase from zero to the maximum values of 0.11, 0.13 and 0.14 when H/L is equal to 0.25, 0.5 and 1.0 respectively. These values then decrease towards zero as W/L is increased.

The relationship between the perturbation pillar load and pillar-opening dimensions can be found as follows:-

$$\frac{P_2}{qH} = (a_2 Z + b_2)(e^{-c_2 X/Z^f} - e^{-d_2 X/Z^g}) \qquad (2)$$

where:

P_2 = perturbation pillar load caused by excavation in an infinite medium which is subject to the horizontal stress field only

q = horizontal field stress

Z = H/L

X = W/L

H = pillar height

W = pillar weight

L = opening width

a_2 = -0.09 This constant is quite sensitive. By rounding off a_2 to -0.1, the maximum tensile load will be increased by 5%.

$b_2 = -0.1$

$c_2 = 0.2$

$d_2 = 2.5$

$f = 0.2$

$g = 1.3$

Pillar Load Under Vertical and Horizontal Stress Field

By superposition, the total pillar load, P, can be found from the following expression:-

$$P = pW + P_1 + P_2 \tag{3}$$

Subsituting equations 1 and 2 into 3, we obtain:

$$\begin{aligned} P &= pW + pL(1 - (a_1Z + b_1)e^{-c_1X} - (1 - a_1Z - b_1)e^{-d_1X}) \\ &\quad + qH\,(a_2Z + b_2)(e^{-c_2X/Z^f} - e^{-d_2X/Z^g}) \\ &= pL\,(\frac{W}{L} + (1 - (a_1Z + b_1)e^{-c_1X} - (1 - a_1Z - b_1)e^{-d_1X}) \\ &\quad + \frac{q}{p}\frac{H}{L}(a_2Z + b_2)\,(e^{-c_2X/Z^f} - e^{-d_2X/Z^g})) \\ &= pL\,(X + (1 - a_1Z + b_1)e^{-c_1X} - (1 - a_1Z - b_1)\,e^{-d_1X}) \\ &\quad + kZ\,(a_2Z + b_2)\,(e^{-c_2X/Z^f} - e^{-d_2X/Z^g})) \\ &= pL\,(X + (1 - (0.4(Z + 1))\,e^{-2X} - (0.6 - 0.4Z)\,e^{-16X}) \\ &\quad - kZ\,(0.09\,Z + 0.1)(e^{-0.2X/Z^{0.2}} - e^{-2.5X/Z^{1.3}})) \end{aligned} \tag{4}$$

Equation 4 indicates that pillar loads will be reduced when openings are excavated in the ground which have a high coefficient of tectonic pressure, k, or q/p. Consequently, clearances between openings can be reduced.

Equation 4 can also be used to determine vertical clearance between the openings by rotating the model to 90 degrees.

Simplified Pillar Load Equations

For a conservative pillar load design, the effect of horizontal field stress can be neglected and a small value of z should be chosen, i.e., $Z = 0.25$. Therefore, equation 4 can be rewritten as follows:-

$$P = pL \left(X + \left(1 - 0.5 \left(e^{-2X} + e^{-16X}\right)\right)\right) \quad (5)$$

When X lies between 0.125 to 3 the engineering equation can be further simplified as shown below:-

$$P = pL \left(X + \frac{0.40 + 3.15\ X}{1 + 2.9\ X}\right) \quad (6)$$

Figure 5 shows the comparison of the pillar loads calculated from equations 4,5 and 6, assuming k = 2.0, and Z = 0.25, 0.5, 1.0. It shows that equations 5 and 6 give more conservative loads than equation 4 and the calculated values from equations 5 and 6 are in good agreement.

The average pillar stress, σ_p, can be determined by dividing the pillar load, P, by pillar width, W, i.e.:-

$$\sigma_p = \frac{P}{W} \quad (7)$$

CONCLUSIONS

1. Equation 4 is developed for predicting pillar load, so that mining engineers can determine optimum horizontal and vertical clearances between two symmetrical rectangular openings. This equation should be applicable for the assumptions and parameter ranges made in the study, i.e., linear elastic homogeneous material and the ratio of pillar height to opening width less than 1.0. It can be applied for determining clearances of underground services/garage stations that are located in the ground which consists of one rock type and has insignificant geological structural features.
2. Equations 5 and 6 are given for predicting pillar loads in case of conservative design approaches by neglecting the effects of horizontal field stress. Equation 6 should be applicable for the pillar width/opening width ratio ranges from 0.125 to 3.
3. To obtain the optimum vertical clearances between two openings, parameters in equations 4,5 and 6 should be rotated by 90 degrees.

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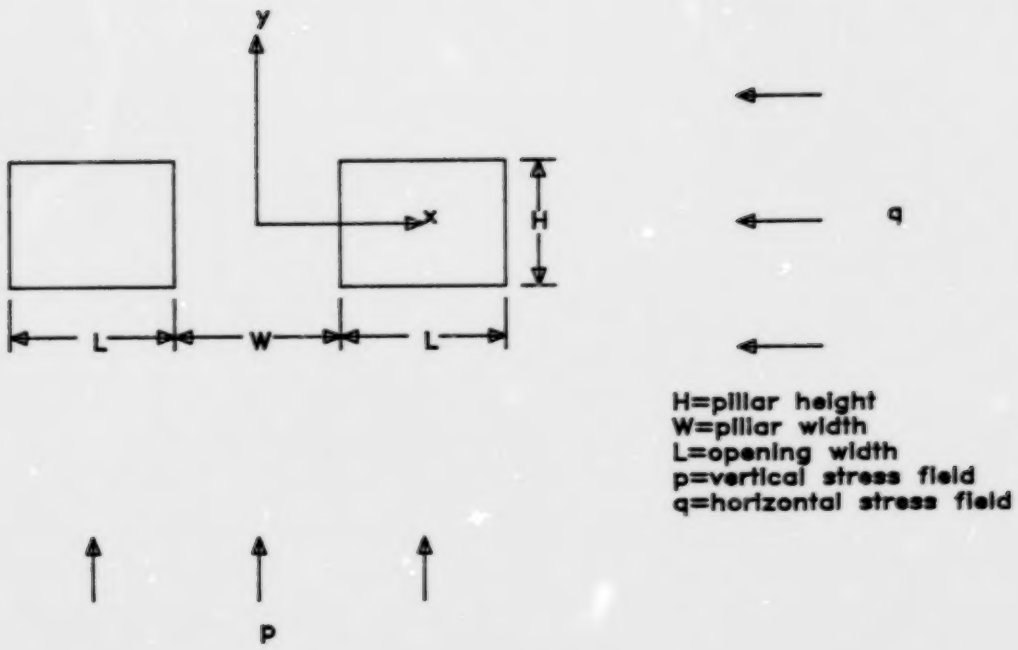

Fig. 1 Loading conditions and dimensions of two symmetrical rectangular openings in an infinite medium

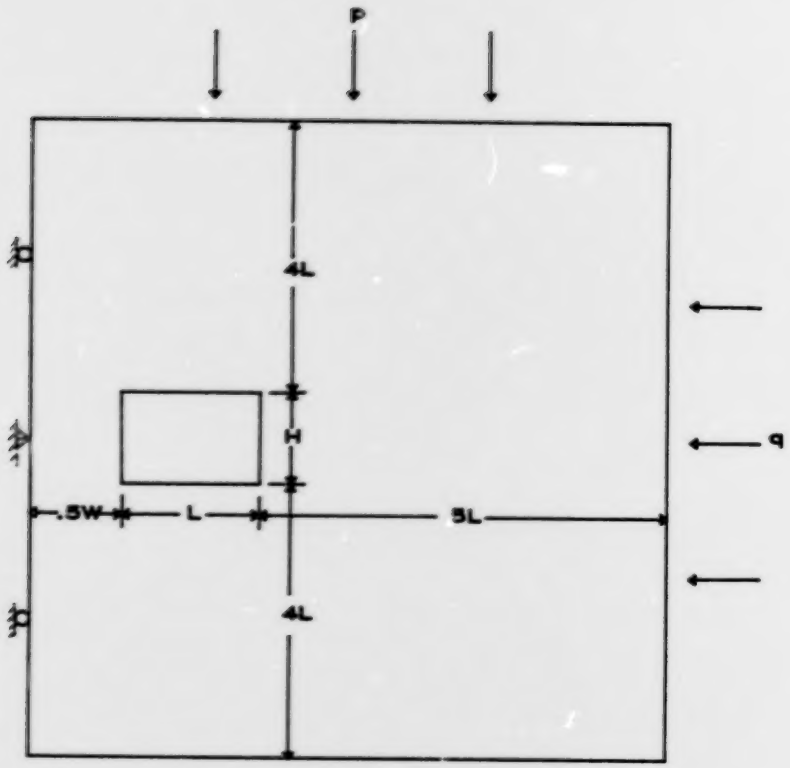

Fig. 2 A typical finite element model

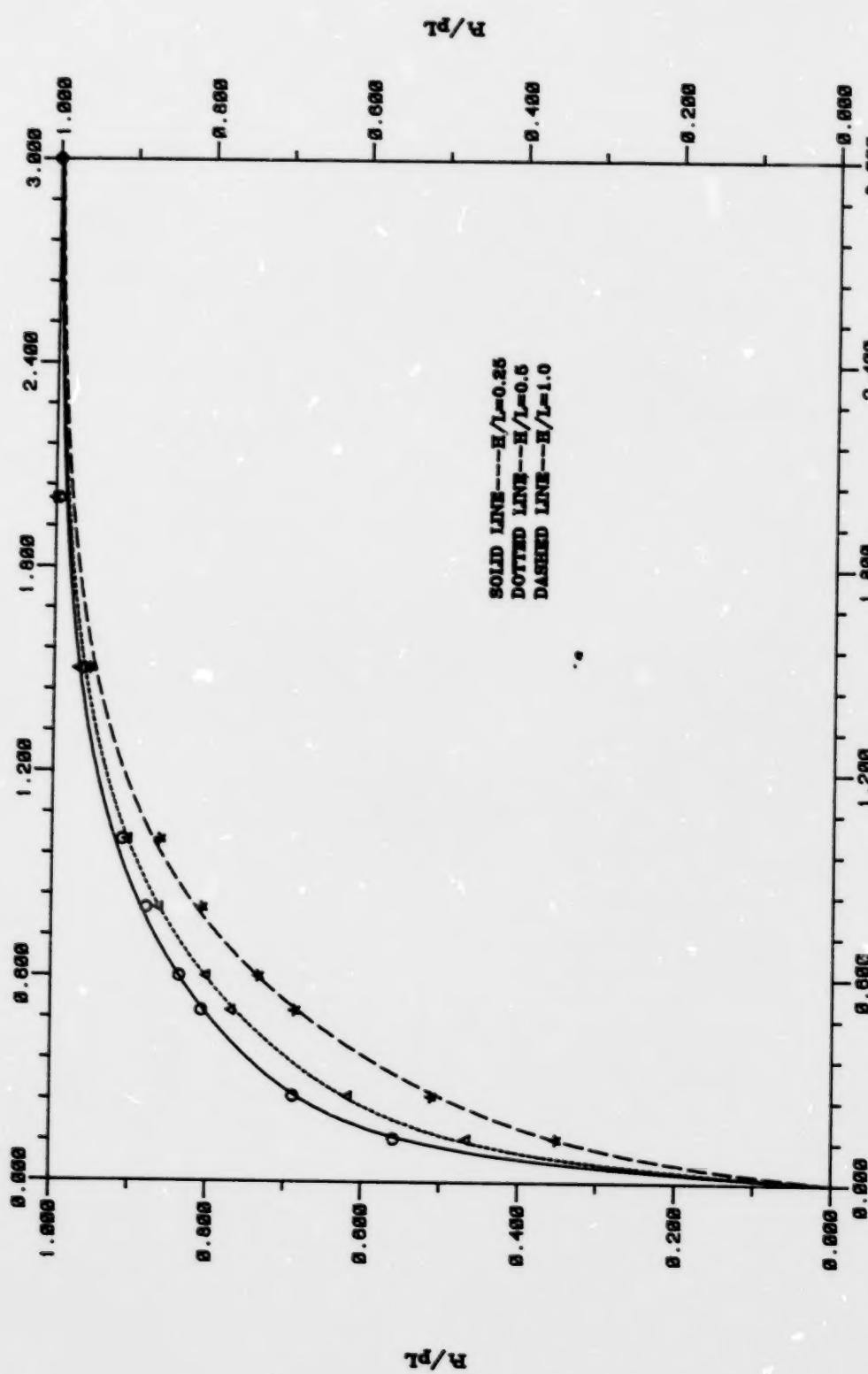

FIG. 3 VARIATION OF P_L/pL WITH H/L, q=0

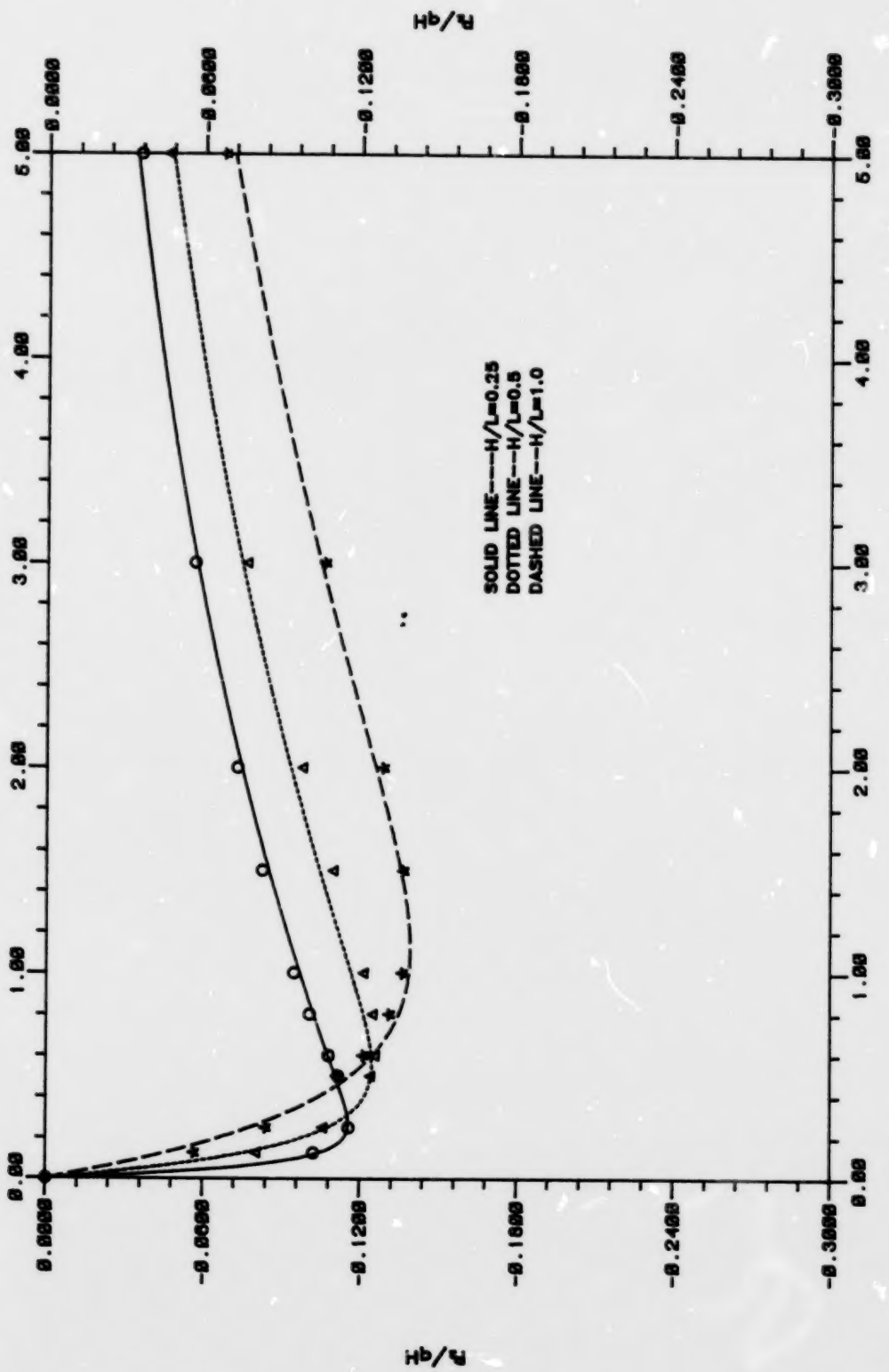

FIG. 4 VARIATION OF P_e/qH WITH H/L, p=0

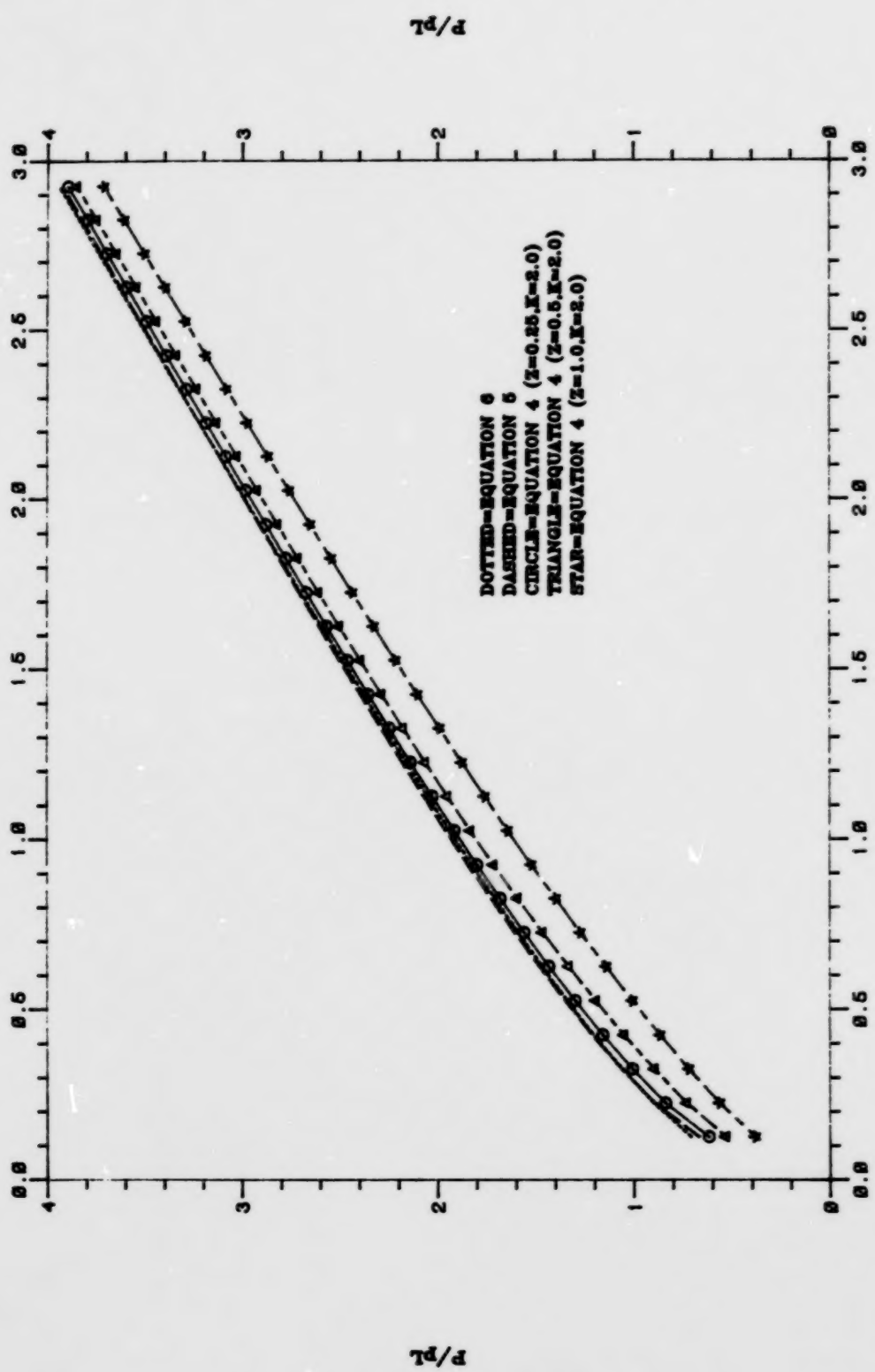

FIG. 5 COMPARISON OF PILLAR LOADS